ANALYSIS

Of a COURSE of

LECTURES

ON

MECHANICS,
HYDROSTATICS,
HYDRAULICS,
PNEUMATICS,
ELECTRICITY, and
ASTRONOMY,

READ BY K

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The SIXTH EDITION.

Nil tam difficile eſt quod non ſolertia vincat.

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LECTURE I.

On MECHANICS.

WHEN two bodies are ſuſpended upon any machine or engine, ſo as act againſt one another, if the engine be put into motion, and the lighteſt body moves through as much more ſpace than the heavieſt, as the weight of the heavieſt exceeds the weight of the lighteſt, the bodies will balance or ſupport each other.

Upon this principle, the force, power, or advantage of any machine, whether ſimple or compound, is eaſily computed: for it is always as great as the velocity of the power applied to work the machine exceeds the velocity of the weight to be raiſed, or the reſiſtance to be overcome: proper allowance being made for friction.

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The machines whereby power is gained, are called *mechanical powers.* They are ſix in number, *viz.* the *lever*, the *wheel and axle*, the *pulley*, or rather ſyſtem of pullies, the *inclined plane*, the *wedge*, and the *ſcrew.*—Of theſe, all ſorts of mechanical engines do conſiſt: and in treating of them, ſo as to ſettle their theory, we conſider them as mathematically exact and perfect, and moving without friction.

A *lever* is a bar, turning upon a prop, or center of motion; and is uſed either to raiſe weights or overcome reſiſtances.—When the lever is put into motion, the velocity of each point of it is directly as the diſtance of the point from the prop. The two parts of the lever, which are on the oppoſite ſides of the prop, are called the *arms of the lever*; and a man can raiſe as much more weight by this machine than he could do by his natural ſtrength without it, as the length of the arm to which he applies his power or force exceeds the length of the other arm which is applied to raiſe the weight.

In the *wheel and axle*, where the power is applied to the wheel, and the weight is raiſed by a rope coiling round the axle, the velocity of the power is to the velocity of the weight as the circumference of the wheel is to the circumference of the axle: and the power or advantage gained by this machine is in the ſame proportion.

A ſingle *pulley* that only turns on its axis, and does not riſe with the weight, ſerves only to change the direction of the power: for it gives no mechanical advantage thereto.

When, beſides the upper pullies which turn round in a fixed block, there is a block of pullies which riſe equally with the weight; the velocity of the weight is to the velocity of the power as one is to twice the number of pullies in the moveable block: and the power and weight balance each other, when the power is in proportion to the weight as one is to twice the number of pullies in the moveable block.

A weight raiſed, or reſiſtance overcome, by an *inclined plane*, moves only through a ſpace equal to the height or thickneſs of the plane in the time that the power drives the plane through a ſpace equal to its whole length. Hence, the velocity of the power is in proportion to the velocity of the weight, as the length of the plane is to its thickneſs or height; and the power and weight balance each other when the power is to the weight as the thickneſs of the plane is to its length.

A *wedge*, in the common form, is like two inclined planes joined together at their baſes, and the thickneſs of theſe planes make the back of the wedge, to which the power is applied in cleaving of wood.

When two equal reſiſtances act perpendicularly againſt oppoſite ſides of the wedge, and a power acts perpendicularly againſt the back of the wedge, the velocity of the power is in proportion to the velocity of the reſiſtance, on either ſide of the wedge, as the length of the wedge is to half the thickneſs of its back: and the power balances the reſiſtance of the wood, when the power is in proportion to the reſiſtance as half the thickneſs of the wedge at its back is to the length of either of its ſides, if the ſharp edge goes to the bottom of the cleft in the wood. But, when the wood ſplits before the wedge, as it generally does, the power and reſiſtance balance each other, when the power is to the reſiſtance as half the thickneſs of the back of the wedge (when it is driven quite into the wood) is to the whole length of the cleft below the back of the wedge.

In the *ſcrew*, the velocity of the power is in proportion to the velocity of the weight raiſed, or reſiſtance overcome, as the circumference of a circle deſcribed by the power in one turn of the ſcrew, is to the diſtance between the ſpirals of the ſcrew: and the power and reſiſtance balance each other, when the former is to the latter, as the diſtance between the ſpirals is to the circumference of the circle deſcribed by the power, which is generally applied to the end of a lever or bar, put through the ſhank of the ſcrew.

In raiſing weights by all ſorts of machines or engines, the time that is loſt in working them is as much as the power gained by them. That is, if a man can raiſe an hundred weight, by his natural ſtrength, to any given height, and has forty hundred weight to raiſe to the ſame height by a machine to which he applies his natural ſtrength or power; he will be forty times as long in raiſing the weight by the machine as he would be in raiſing a fortieth part of it by his own ſtrength without any machine at all.

In raiſing a weight by any machine, as much more power muſt be applied than that which is ſufficient to balance the weight, as the friction of the machine amounts to.

If machines could be made without friction, the leaſt degree of power added to that which balances the weight would be ſufficient to raiſe it. In the lever, the friction is next to nothing; in the wheel and axle it it but ſmall; in the pullies it is very conſiderable; and in the inclined plane, wedge, and ſcrew, it is very great.

Cranes, for raiſing great weights, conſiſt of trundles, wheels, axles, pullies, a gib, a handle or winch, and a catch or ſtop to prevent the running down of the weight, if the workers of the crane ſhould happen inadvertently to quit their hold of the winch.—The great crane at *Briſtol* is reckoned to be the beſt and ſafeſt one in Europe.

Pyrometers are machines for meaſuring the degrees of expanſion of metals by heat. They are made of various forms, which cannot be deſcribed here. The one which is uſed in theſe lectures ſhews the expanſion of metals to the 90,000dth part of an inch.

LECTURE II.

On MECHANICS.

THE *center of gravity* of a body is a point, round which all the parts of the body balance each other; and the body deſcends by its own weight in the ſame manner that it would do if its whole weight were accumulated in that point. Therefore, the weight of a body will cauſe it to fall, if its center of gravity be not ſupported.

If a perpendicular, let fall from the center of gravity, falls within the baſe, or part of the ground on which the body is placed, the body will ſtand: otherwiſe, it will tumble or fall.

A *cylinder* is ſupported on an inclined plane, by a power which is in proportion to the weight of the cylinder, as the height or thickneſs of the plane is to the length of the plane. If the power be leſs, the cylinder will run down the plane; if greater, it will be drawn up. Hence, when the weight of a loaded *cart* or *waggon*, and the angle of the hill's height, are known, the power required to ſupport the load on the hill may be found. And if the power be encreaſed, ſo as to overcome the friction of the axles of the wheels, the load will be drawn up.

Thus, ſuppoſing the ſide of the hill to be a ſmooth plane, and the angle of its height to be 7 degrees 14 minutes *, the perpendicular height of the hill is, in that caſe, equal to the eighth part of the length of its ſide; and the power that balances the load thereon is equal to an eighth part of the weight of the load.

If the angle of height be 14 degrees 28 minutes, the height of the hill is equal to a fourth part of the length of its ſide: and a power equal to a fourth part of the load will balance it.

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* A minute, in this ſenſe, is the 60th part of a degree.

If the angle of height be 22 degrees 2 minutes, the height of the hill is equal to three eighth parts of the length of its ſide: and a power equal to three eighth parts of the load will balance it.

If the angle of height be 30 degrees, the height of the hill is equal to half the length of its ſide: but this would be rather too ſteep for any cart or waggon; becauſe the horſes would have great difficulty in fixing their feet on the ground. — Whenever this happens, if a man would get upon the back of each horſe, their weight would be encreaſed, and the horſes could fix their feet ſo much the better, which would not diminiſh their power of drawing.

It is proved by two models of carts, one of which has its wheels twice as big as thoſe of the other, that when they are loaded with equal weights, it requires twice as much power to draw the cart which has the ſmaller wheels, as to draw the other whoſe wheels are larger.

It is alſo proved, by two models of waggons, one of which has broad wheels and the other narrow ones, that broad wheels are juſt as eaſily drawn on plain hard ground as narrow ones; and eaſier on ſandy or rough ground, becauſe they ſink not ſo deep into the earth.—It is alſo plain by experiment, that whether the wheels be broad or narrow, the waggon is much eaſier drawn either on rough or ſmooth ground, when the heavieſt part of the load is put over the axle of the hind wheels, which are the biggeſt, than when it is put over the axle of the ſmall fore wheels.

In *water-mills*, the velocity of the float boards of a *breaſt wheel*, or buckets of an *overſhot wheel*, ought to be equal to a third part of the velocity of the water where it turns the wheel; and the train ſhould be ſuch, that the grinding ſtone may make about 60 revolutions in a minute.

The number of rounds, or upright ſtaves in the trundle, ſhould be no aliquot part of the number of cogs in the wheel that turns the trundle: for, when they are not, each cog will fall upon a different ſtaff from what it did laſt before: and, by that means, they will all wear more equally than if it took the ſame ſtaff in each revolution.

In *mills* for *ſawing timber*, either by means of wind or water, the ſaws are moved up and down by cranks on the axle of a trundle turned by a wheel; and the timber is gradually drawn forward to the ſaws by the ſlow motions of wheels, which are pulled round, tooth after tooth, by hooks in levers moved up and down by the ſaws.

It is proved by experiments, that the *power of the wind*, on wind-mill ſails, is as the *ſquare of the velocity of the wind:* that is, four times as great when the velocity of the wind is double; nine times as great when the velocity is triple; ſixteen times as great when the velocity is quadruple; and ſo on.

When the wind blows but one mile in an hour, we can hardly ſay *that we feel it*: when it blows or moves from two to three miles in an hour, it is *juſt perceptible:* from four to five miles in on hour, we call it *a gentle pleaſant wind:* from 10 to 15 miles, *a pleaſant briſk gale:* from 20 to 25 miles, *very briſk:* from 30 to 35 miles in an hour, *high wind:* from 40 to 45 miles, *very high:* at 50 miles, *a ſtorm* or *tempeſt:* at 60 miles, *a great ſtorm:* at 80 miles, *a hurricane:* and, at 100 miles in an hour, *a hurricane that tears up trees* and *carries buildings*, &c. before it.

The *engine* by which the *piles* were driven at *Weſtminſter*-Bridge was ſo contrived, that when the horſes that turned it went conſtantly round the great ſhaft, a weight was drawn up to a great height, then let fall freely upon the top of the pile, and was immediately followed by a pair of tongs which took hold of the weight and drew it up again, A large fly regulated the motion, and acted againſt the horſes to keep them from falling forward when the weight dropt. The tongs were nearly counterpoiſed by another weight, whoſe ſmall rope wound upon a ſpiral fuſy, ſo as to cauſe the tongs to fall with a moderate and uniform velocity.

LECTURE III.

On HYDROSTATICS.

FLUIDS preſs equally in all manner of directions, as is ſhewn by their riſing in four glaſs tubes open at each end; one tube being quite ſtraight, another bent directly upward at the lower end, a third bent ſideways to a right angle, and a fourth bent obliquely. All theſe tubes being put into water, almoſt to their tops, the water riſes in each of them to a level with the ſurface of the water in which they are immerſed.

If an empty phial, heavy enough to ſink in water, be corked, and ſuſpended by a thread at one end of a balance, then immerſed in water and counterpoiſed by weights in a ſcale at the other end of the beam; upon pulling out the cork, and letting the phial fill with water, it will deſcend; and will then require as much additional weight put into the ſcale, to counterbalance the phial, as will weigh all the water in air that filled it up to the cork. This ſhews, that fluids weigh as much in their own elements as they weigh in air.

Let a box have a moveable bottom, to fit ſo cloſe as that it may loſe no water, and yet be eaſily moved up and down; the box having a round hole in the cloſe lid, to receive the lower end of a long tube of glaſs which is open throughout; and let a thread which is faſtened to the bottom, and comes up thro' the tube, be tied to one end of the beam of a balance: Let the box be made to hold a pound of water, which is balanced on the bottom by a pound weight in a ſcale hung to the other end of the beam: Then if another pound be put into the ſcale, it will draw up the bottom a little, and cauſe the water to riſe in the tube, as high above the lid of the box as is equal to the depth of the box. If another pound be put into the ſcale, it will cauſe the water to riſe twice as high in the tube as the box is deep. If another additional pound be put into the ſcale, it will cauſe the water to riſe three times as high in the tube as the box is deep; and ſo on.—This ſhews, that the preſure of fluids is directly in proportion to their perpendicular heights, without any regard to their quantities.

If a piece of lead, whoſe upper ſide is flat, be put into an empty veſſel; and a piece of wood, whoſe under ſide is flat, be laid upon the lead, ſo as no water may get in between them; and the wood be held down till the veſſel be filled with water; the wood will remain upon the lead at bottom: for it is then kept down, both by its own weight, and the weight of the water above it: the upward preſſure of the water being prevented, becauſe none gets in between the lead and the wood.

If a wide tube, open at both ends, has a piece of lead held cloſe to its lower end, by a ſtring within the tube, ſo as no water can get in between the lead and the tube; and then, if the whole be immerſed in water, till the depth of the lead below the ſurface of the water in the veſſel be almoſt twelve times the thickneſs of the lead; the ſtring may then be let go: for the lead will not fall away from the tube, becauſe the upward preſſure of the water, at that depth, is greater than the weight of the lead, and no water gets above it to preſs it down.—But if the tube and lead be drawn up till the depreſſion of the lead below the ſurface of the water in the veſſel is any thing leſs than $11\frac{1}{3}$ times the thickneſs of the lead, it will then fall off; which ſhews, that lead is $11\frac{1}{3}$ times as heavy as its bulk of water.

If a tube, three or four inches wide, and open at both ends, has a wet bladder tied over one end, ſo as the bladder may be flaccid; and ſome water be then poured into the tube, it will preſs the bladder downward, and make it concave within, below the tube. But, if that end be immerſed in a veſſel of water, till the ſurface of the water within the tube be even with the ſurface of the water in the veſſel without it, the bladder will then be flattiſh, as if it were nor preſſed at all, becauſe it is equally preſſed on both ſides. If it be plunged deeper, the bladder will be preſt upward, ſo as to be convex within the tube: if it be raiſed higher, it will be more preſt downward than upward, and be concave within. This ſhews, that the preſſure of fluids depends upon their height, without any regard to their quantity.

If a ſmall tube be joined to a very large one, and the whole be bent in the middle, ſo as the two parts may be parallel, or make any angle; water may be poured into either tube, and it will riſe juſt as high in the other, and ſettle in both, with ſurfaces parallel to the horizon, when you leave off pouring; even tho' one tube ſhould contain ten thouſand times as much as the other; this ſhews, that the ſmalleſt quantity of a fluid will balance the greateſt quantity whatever, at equal heights, if they join at bottom: and that water in pipes will aſcend to the level of the ſpring from whence it came.

If a ſmall tube, about two feet long, and open throughout, has one end bent to a right angle, and the open neck of a bladder be tied round that end; if then the bladder be put into a box, and have a board put upon it with twenty pound weight laid upon the board; and the tube be held upright, and water be poured into it, the water will run into the bladder, and raiſe all the weight. And, by the time that the water ſtands about 20 inches high in the tube, it will ſupport the weight, although the bore of the tube were ſo ſmall as not to contain an ounce of water.

Let a piece of light wood be put into one ſcale of a common balance, and as much water be put into the other ſcale as will counterbalance the wood. Then, let the wood be taken out of the ſcale, and put into a glaſs, brim full of water; the wood will cauſe as much water to run over the brim as is equal in bulk to that part of the wood which goes below the ſurface of the water. Then, take the wood out of the glaſs, and pour in the water from the ſcale that balanced the weight of the wood; and it will fill the glaſs up to the brim again. This proves, that a quantity of water equal in bulk to the immerſed part of the wood, is juſt as heavy as the whole of the wood: and conſequently, that the quantity of water diſplayed by a ſhip is equal to the whole weight of the ſhip and her cargo.

The preſſure of a fluid, upon the bottoms of all veſſels whatever, is proportional to their baſes and perpendicular heights, without any regard to the quantities they contain.—This is ſhewn by two veſſels of equal baſes and heights but of very different capacities; their bottoms being kept up by equal forces; for, at whatever height the water is in one veſſel when it preſſeth off the bottom, it does the like when poured in to the ſame height in the other.

A *ſyphon* will not run, unleſs the perpendicular height of the column of fluid in the outer leg be greater than the perpendicular height of the column in the inner leg above the ſurface of the fluid in the veſſel in which that leg is partly immerſed.

By the *Tantalus Cup*, and two other machines, the cauſe of the ebbing and flowing of wells, and of intermitting and reciprocating ſprings, is explained.

LECTURE IV.

On SPECIFIC GRAVITIES, *and* HYDRAULIC ENGINES.

A Body lighter than its bulk of a fluid, will ſwim therein; if heavier, it will ſink: if of equal weight, it will reſt any where between the top and bottom of the fluid.

If a ſolid body, heavier than its bulk of a fluid, be immerſed and ſuſpended therein, it will loſe as much of its weight as its bulk of the fluid weighs: but the weight loſt by the ſolid, will be imparted to the fluid. Hence, all equal bodies, immerſed and ſuſpended in fluids, will loſe equal weights therein: and unequal bodies will loſe weights proportionable to their bulks.

If the weight of a body in air be divided by what it loſes in a fluid, the quotient will ſhew how much heavier it is than its bulk of that fluid; or its ſpecific gravity.

By this trial, pure gold if found to be 19.637 times as heavy as its bulk of water: Guinea gold 17.793 times as heavy: quickſilver 14.000 times: lead 11.325 times: ſtandard ſilver 10.535: copper 9.000: plate braſs 8.000: ſteel 7.852; and iron 7.645.—A cubic foot of common water weighs 1000 avoirdupoiſe ounces: and if the decimal point be taken away from the aboves numbers, and they be reckoned to be whole, they will ſhew how many avoirdupoiſe ounces are contained in a cubic foot of each of the above mentioned bodies.—Thus a cubic foot of pure gold weighs 19637 ounces; a cubic foot of Guinea gold 17793; and ſo on.

A cubic inch of braſs, or any other metal, loſes $253\frac{1}{5}$ grains, of its aereal weight in water; in proof ſpirits it loſes 235 grains. Hence, a cubic inch of water weighs $253\frac{1}{5}$ grains, and a cubic inch of proof ſpirits 235.

In *a common pump*, as the piſton is raiſed above what is called the ſucking valve, the water riſes by the preſſure of the atmoſphere to the height of about 32 feet, in that part of the pump out of which the air is liſted by the piſton. Therefore, the piſton (or bucket) muſt always work within 32 feet of the ſurface of the water in the well: otherwiſe, the water will never get above it. But, at any diſtance, leſs than 32 feet from the ſurface of the well, the water will riſe above the bucket; and then, it may be lifted to any height whatever, by applying a ſufficient degree of power to the handle.

In *a forcing pump* the water riſes above the ſucking valve, by the preſſure of the atmoſphere, as in the common pump. But, inſtead of a bucket with a valve in it, there is a ſolid plunger, that fits the pump-bore ſo, as neither water nor air can get between. The plunger, in deſcending, forces the water through a ſide pipe into an air veſſel, through a valve therein; and a pipe is fixed into the top of the air veſſel, and comes down almoſt to reach the valve. As the water is forced into this veſſel, above the end of the pipe, it compreſſes the air within; and the force of the compreſſed air, acting on the water, drives it out of the air veſſel, up the pipe; the height of which muſt be in proportion to the degree of power applied to the handle of the pump.

On this principle, *engines* are made for *extinguiſhing fire*, and for raiſing water to gentlemen's ſeats which are above the level of rivers or ſprings.—If ſuch an engine has a quadruple crank, for working four forcing pumps, by means of a wheel turned by water, or by horſes; and all the pumps throwing the water into one common pipe, the water may be forced up to any given height anſwerable to the power that turns the wheel.

A wheel, that is turned by water, may have buckets hung to its ring, all around. As the buckets dip into the water, each will bring up as much as fills it, to the top of the wheel; and, at that height, the water may be thrown into a ciſtern, and conveyed from thence in pipes.

The great engine at London-Bridge, for raiſing water to ſupply the city, conſiſts of a large water-wheel, on the axis of which are two wheels with ſpur cogs, each turning a trundle which has four cranks on its axis, moving ſo many levers up and down; and each lever works a forcing pump, by moving its plunger up and down in the pump barrel.

There is a hill near one of the *Hungarian* mines, having a fine ſpring 145 feet above the plain ſurface of the ground. The water is let down from this ſpring into a cloſe veſſel ſtanding on the ſurface of the ground; and a ſmall air-pipe goes from that veſſel down to another veſſel at the bottom of the mine; and a pipe goes from that laſt veſſel up to the ſurface of the ground.—The water that runs down into the former veſſel forces the air out of it, down into the veſſel in the mine; and the air, being compreſſed on the water which is let into that veſſel from the mine, drives the water out of that veſſel, up through the pipe, which is 104 feet high, to the ſurface of the ground, where the water runs off: and, by this means, the water is raiſed from the mine.—There are ſeveral cocks in this engine, which are opened and ſhut occaſionally, by men who attend for that purpoſe.

Mr. *Blakey's fire engine* acts upon this principle: only he compreſſes the air by ſteam from a boiler, which is placed above ground. The air, thus compreſſed in a cloſe veſſel, is forced down a pipe, into a veſſel filled with water in the bottom of the mine: and the force of the compreſſed air drives the water out of that veſſel, up through a pipe, to the ſurface of the ground. And thus, by the opening and ſhuting of ſome cocks, the veſſel in the mine is emptied at each ſtroke.

LECTURE V.

On PNEUMATICS.

THE principal parts of the *air-pump* are ſo much like thoſe of the water pump, that whoever underſtands the one will be at no loſs to underſtand the other. The uſe of this engine is to exhauſt the air out of glaſs veſſels, generally called *receivers*.

If a glaſs of water be placed under a receiver which has a round hole at top, and a piece of wood be cemented into that hole, and the lower end of the wood go down into the water, and the top of the wood be about an inch above the receiver; let the top be covered by one's thumb, and the receiver exhauſted of air; then if the thumb be taken off, the air will ruſh into the water under the receiver, and make a great bubbling therein. But, cover the top of the wood again, and the bubbling will ceaſe.—This ſhews that no air can paſs through the lateral pores of the wood into the longitudinal pores thereof.

A bell will not ring under an exhauſted receiver; which ſhews that there can be no ſound without air.

In a tall receiver, exhauſted of air, the down of a feather will fall as ſoon from the top to the bottom as a guinea will: which ſhews that all bodies fall equally quick *in vacuo*.

A veſſel that holds two quarts, is found to be 32 grains lighter when the air is exhauſted out of it, than it was when full of air.—This ſhews, that a quart of air (in Engliſh wine meaſure) weighs 16 grains.

If a perſon puts his hand on the top of an open receiver, which is about 2 inches wide, and the air be exhauſted out of the receiver, his hand will be held down ſo faſt by the preſſure of the atmoſphere, that he cannot get it off until the air be let into the receiver again.

The weight of the air breaks a bladder, tied over the top of an open receiver, when the air is exhauſted out of it.

If one end of a bit of dry haſel branch be fixed into a hole in the bottom of a cup, and the other end into a hole in the top of a receiver, and ſome quickſilver be poured into the cup; if then the receiver be exhauſted of air, the preſſure of the atmoſphere will force the quickſilver down through the pores of the wood, into the receiver.

If a glaſs tube, about 32 inches long, and open at one end, be filled with quickſilver, and the open end placed in a jar of quickſilver, and the whole covered with a tall receiver; the preſſure of the atmoſphere on the quickſilver in the jar will keep it up in the tube, as high as it then ſtands in the barometer. But, if the receiver be exhauſted of air, all the quickſilver will deſcend out of the tube into the jar: and, upon letting the air into the receiver again, its preſſure will force the quickſilver up into the tube again, as high as it was before: which ſhews, that the quickſilver in the barometer is kept up by the preſſure of the air.

If a pump be placed in water, under a receiver, and the air be exhauſted, no water can be raiſed by working the piſton, until the air be let in again: which ſhews, that the water riſes in pumps by the preſſure of the air, and not by any ſuch thing as ſuction.

And, by an experiment with two receivers, one placed under the other, it is proved to a demonſtration, that the receivers are held down on the pump plate by the preſſure of the atmoſphere; not by ſuction of the pump.

If a pipe be fixed into a plate which covers the open end of a tall receiver, and the air be exhauſted; if then the pipe be put into a baſon of water, the preſſure of the air will force the water upward, ſo as to make a fountain in the exhauſted receiver.

If the air be exhauſted out of two braſs hemiſpherical cups, joined together only by a wet leather between them; if the diameter of each cup be $5\frac{1}{2}$ inches, it will require a force equal to 360 pounds to ſeparate them: ſo ſtrongly are they held together by the preſſure of the atmoſphere.

LECTURE VI.

On PNEUMATICS.

IF a leaden weight, of two or three pounds, be fixed to the end of a ſyringe, and held down till the piſton be drawn up, and the air thereby lifted out of the ſyringe; the lead and ſyringe will then be forcibly puſhed up on the piſton, by the upward preſſure of the external air.

If a large cork be exactly counterbalanced in air by a piece of lead, and covered with a cloſe receiver, and the receiver be then exhauſted; the cork will preponderate, and ſhew itſelf to be heavier than the lead.

If a lighted candle be placed under a cloſe receiver that holds a gallon, the candle will burn a minute, and no longer: which ſhews that a candle requires a gallon of freſh air every minute to feed its flame. When the flame goes out, the ſmoke will continue to aſcend: but upon exhauſting the receiver of air, the ſmoke will fall down to the bottom of the receiver: which ſhews that ſmoke is not deſtitute of weight; but that it aſcends in air becauſe it is lighter than air.

If a little air be tied up in a bladder, and the bladder be covered with a cloſe receiver; upon exhauſting the air out of the receiver, the air confined in the bladder will expand ſo, as to make the bladder appear full blown, but, on admitting the air into the receiver again, the bladder will be preſſed into its former ſhrevelled ſtate.

If the ſame bladder be put into a box, and have 16 or 20 pound weight of lead put upon it, and then be covered with a receiver, and the receiver exhauſted of air, the air confined in the bladder will raiſe up the leaden weights by the force of its ſpring.

Moſt ſorts of animals will die in the greateſt agonies in an exhauſted receiver.

If a tall receiver be exhauſted of air, and joined by a pipe to a cloſe air-light veſſel about half full of water, the ſpring of the air in the veſſel will force the water up into the receiver, and make a fountain therein.

By a machine called the *transferrer*, it is proved that the receivers are held down on the pump by the weight of the air.

If a glaſs of warm beer be put under a receiver, and the receiver be exhauſted; the beer will ſhew all the appearance of boiling, as the air comes out of it by the force of its ſpring.

If about a cubic inch of dry wainſcot be put in a glaſs of warm water, and covered with a receiver; on exhauſting the receiver, the water will firſt ſeem to boil, as the air comes out of it: and then, an amazing quantity of air will come out of the wood and bubble in the water.

If a long glaſs tube, open at both ends, be cemented into the top of a jar, about half full of quickſilver, and covered with a tall receiver, and the receiver be exhauſted; the ſpring of the air in the jar will force the quickſilver as high up in the tube as it roſe formerly by the preſſure of the air: which ſhews, that the ſpring of the air is juſt as ſtrong as its preſſure.

If a receiver be exhauſted of air, and then the air be let into it through the flame of a candle, held to the end of a pipe which opens into the receiver through a braſs cover; the receiver will be filled with burnt air. If then the cover be taken off, and an animal be put into the receiver, it will die: or, if a candle be put into the receiver, it will go out immediately.

LECTURE VII.

On ELECTRICITY.

ALL the electric fire or fluid comes from the earth to the *electrifying machine*, and is rubbed out by the cuſhion on the glaſs globe. This fire circulates round the globe, to the ſharp points of a metal bar, called the *conductor*; and will ſnap againſt one's finger when held near the conductor.

The jars belonging to this machine are coated on the out-ſide, and lined on the inſide, with tinfoil; to about two inches ſhort of the top. A cork is put into each jar, and a braſs wire is put down through the cork ſo as to touch the lining at bottom: and a round knob is fixed to the top of each wire above its reſpective jar.

If ſuch a jar be placed on a table, ſo as the knob may touch the conductor, and the globe be then turned round; the electric fire will go off from the conductor, by the knob and wire, into the jar, and be condenſed in its inſide: and the table will carry off as much fire from the out-ſide as goes into the in-ſide. So that, the in-ſide of the jar will have more than its natural quantity of fire; and the outſide as much leſs.

Then, if a perſon holds a bended wire in his hand, and firſt touches the outſide coating with the lower end of the wire, and then touches the knob with the other end; a communication will be thereby formed between the coating and lining of the jar, and the fire will be diſcharged from the lining to the coating, with an audible noiſe: but the perſon who holds the wire will receive no ſhock.

If a jar be thus electrified, and a perſon takes hold of it by the coating, with one hand, and touches the knob with a finger of the other, the fire will be diſcharged from the jar through his body; and he will receive a ſhock, which will be felt in his arms and breaſt.

If a chain be hung to the coating of a jar, and the jar be electrified; then, if ever ſo many perſons ſtand ſo as to form a ſort of ring, and all but two join hands; if the firſt perſon of the ring takes hold of the chain in the hand which joins not, and the laſt perſon touches the conductor by a wire in the like hand; the jar will be diſcharged through them all in an inſtant, and each perſon will receive a ſhock.

To confine the ſhock to any part of a perſon's body, as ſuppoſe from the elbow to the wriſt, let one end of a chain be hung to the coating of the jar, and the other end be tied to the wriſt by a ſilk cord or ribbon: then take another chain, and tie one end of it in the like manner to the elbow. This done, let the jar be electrified; whilſt another perſon holds the elbow chain about a foot from the looſe end; and then, if that perſon touches the conductor with the looſe end of the chain; the jar will be diſcharged, and the perſon to whom the chains are tied will receive a ſhock, from chain to chain: but the other perſon who holds the chain will receive nothing of the ſhock.

Such ſhocks are found effectual for curing old ſprains, rheumatic pains, and hard ſwellings: but, before they are given, it would be proper to take many ſparks of electric fire from the part affected; as follows.

Let the affected perſon ſtand on a glaſs-footed ſtool, or on a board ſet upon four glaſs bottles; and take hold of one end of a chain, the other end of which is hung on the conductor.

Then if the globe of the machine be turned by the winch, the perſon will be electrified: and, if another perſon preſents a knuckle of his finger to any part of the electrified perſon's body, the fire will ſnap from that part againſt his finger, every time he preſents it.—A freſh ſcald with hot water, before it riſes into a bliſter, is inſtantaneouſly relieved by taking ſparks from it in this manner.

It is plainly ſhewn in miniature by this machine, that if a metal rod be fixed to a houſe, ſo as the upper end may be about a yard higher than the top of the chimney, and the lower end go down into the ground: if thunder breaks upon the houſe, it will not be hurt thereby; for the rod carries off all the lightning down into the earth. But, if the thunder breaks upon a weather-cock, it will run down to the foot of the iron ſpindle; and then, for want of a further metal conductor to carry it off, the houſe will be damaged.

If a Florence flaſk, or any other thin glaſs of that ſhape be exhauſted of air, and then held to the conductor to be electrified in a dark room; the electric fire will flaſh within the glaſs, and exactly reſſemble the *aurora borealis*.

Small models of compleat *water-mills* may be turned by a ſtream of the electric fluid from a pointed wire in the conductor.

All metals, and water, conduct the electric fire: but ſilk, hair, glaſs, roſin, glue, and wax, do not.

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LECTURE VIII.

On the CENTRAL FORCES, *and Doctrine of the* TIDES.

THE machine by which theſe are ſhewn, is called the *whirling table*.

Matter being inert and unactive, can neither put itſelf into motion, nor ſtop itſelf after it has been put into motion in free ſpace. The cauſe why all bodies ſtop which are put into motion near the earth, is the reſiſtance of the air in which they move, and their own gravity which makes them fall to the earth.

When only one force acts upon a body, and puts it into motion, it can go no way but in the rectilineal direction in which that force impelled it. Therefore, when we ſee a body move in a curve of any kind, we muſt conclude that it is acted upon by two forces at leaſt.

All bodies moving in orbits have a tendency to fly off from their orbits, and move in right lines; as is evident by a pebble whirled round one's hand in a ſling. Therefore, to keep them in their orbits, ſome active power muſt be conſtantly drawing or impelling them towards the center of their orbits.

The planets are retained in their orbits by the power of gravity, and they are moved in their orbits by a projectile force impreſſed upon them by the Deity at the beginning.

The ſun's attraction cauſes or conſtitutes the gravity of the planets: and, if that power alone acted upon them, it would bring them to the ſun. If the projectile force alone acted upon the planets, it would carry them off in ſtraight lines. But, by the proper adjuſtment of theſe two forces, the planets continue to go round the ſun in their reſpective orbits.

The center of gravity between any two revolving bodies is a point in which they are in *æquilibrio:* its diſtance from their centers is inverſely as their quantities of matter.

When one body moves round another, both of them muſt move round their common center of gravity, as is plainly proved by experiment. Hence, the largeſt body in the ſolar ſyſtem could not remain immoveable if any other body moved round it.

The quantity of matter in the ſun is much greater than in all the planets put together. Therefore, the common center of gravity between the ſun and planets is much nearer to the ſun than to any planet in the ſyſtem.

The common center of gravity between the ſun and all the planets is at reſt; but the common center of gravity between any planet and its ſatellite is moveable; and deſcribes the orbit in which the planet itſelf would move if it had no ſatellite.

The common center of gravity between the earth and moon is 6000 miles from the earth's center.—As the earth and moon go round their common center of gravity every month, the earth's center deſcribes a circle of 12000 miles diameter in that time; and conſequently, the earth is 12000 miles nearer the ſun at the time of full moon than at the time of new moon.

All the parts of the earth have a tendency to fly off, in proportion to their diſtance from this center of gravity: therefore, the ſide of the earth which at any inſtant is turned away from the moon has a greater centrifugal force, or tendency to fly off, than the earth's center has; and the earth's center has a greater centrifugal force than the ſide of the earth has which is then turned toward the moon.

At the earth's center, the moon's attraction balances the centrifugal force: conſequently, her attraction on the ſide next her is greater than the centrifugal force on that ſide, and leſs than the centrifugal force on the ſide fartheſt from her. As the moon's attraction on the ſide next her is greater than the centrifugal force there, her attraction cauſeth the tide to riſe on that ſide.

As the centrifugal force on the ſide of the earth fartheſt from the moon is as much greater than her attraction, as her attraction on the ſide next to her is greater than the centrifugal force, the tide muſt riſe as high on that ſide of the earth, which is at any inſtance fartheſt from the moon, by the exceſs of the centrifugal force there, as it riſes on the ſide which is then neareſt the moon by the exceſs of her attraction; as is clearly proved to ſight by an experiment.

A double velocity, in the ſame orbit, balances a quadruple power of gravity, or attraction at the center of that orbit, as is manifeſt by experiment.—Therefore, if the progreſſive velocity of any planet were twice as great as it now is, the ſun's attraction would need to be four times as great, in order to retain the planet in its orbit.

The ſquares of the times in which the planets go round the ſun are found by obſervation to be in the ſame proportion to one another as the cubes of their relative diſtances from the ſun. Hence we find by experiment, that the ſun's attraction diminiſhes in proportion as the ſquares of the diſtance from him encreaſe. That is, at a double diſtance from the ſun, his attraction is four times leſs; at a triple diſtance it is nine times leſs; at a quadruple diſtance it is ſixteen times leſs; and ſo on, throughout the ſyſtem.

The earth is of a ſpheroidal figure, flattened a little about its poles, and ſwelled out about the equator; ſo that its equatorical diameter is longer than its axis, as proved by the French obſervations. This demonſtrates that the earth turns round its axis: for, if it did not, the water would leave the equatoreal regions, and overflow the polar. The whirling ſphere proves, that this figure of the earth ariſes from its motion on its axis.

LECTURE IX.

On the SOLAR SYSTEM.

THE *ſolar ſyſtem* conſiſts of the ſun, ſix planets, ten moons, and the comets.

All the planets go round the ſun, from weſt by ſouth, to eaſt; in orbits nearly circular, and but little inclined to each other.

The ſun's diameter is about 890,000 Engliſh miles, and the earth's is only 7970.—Hence, the ſun is 1,389,900 times as big as the earth.

The ſix primary planets are called *Mercury*, *Venus*, the *Earth*, *Mars*, *Jupiter*, and *Saturn*. The earth has one moon, Jupiter four, and Saturn five; going round them.

The time in which any planet goes round the ſun is the length of its year; and the time in which it turns round its axis is the length of its day and night taken together.

Mercury goes round the ſun in 87 days 23 hours: its diameter is 3000 Engliſh miles, its diſtance from the ſun is 36,841,468 miles, and its hourly progreſſive motion in its orbit is 109,699 miles. The time of its diurnal motion, or length of its day and night, is unknown.

Venus goes round the ſun in 224 days 17 hours: its diameter is 9330 miles, its diſtance from the ſun is 68,891,486 miles, its hourly motion in its orbit is 80,295 miles, and it turns round its axis in 24 days and 8 hours.

The *Earth* goes round the ſun in 365 days 5 hours 49 minutes: its diameter is 7970 miles, its diſtance from the ſun is 95,173,000 miles, its hourly motion in its orbit is 68,243 miles, and it turns round its axis in 24 hours.

The *Moon* goes round the earth, from change to change, in 29 days 12 hours 44 minutes: and turns round her axis in the ſame time. Her different phaſes prove that ſhe ſhines by reflecting the ſun's light, and not by any light of her own. Her diameter is 2170 miles, and her diſtance from the earth's center is 240,000. In reſpect of the earth, ſhe moves 2290 miles every hour, in her orbit.

Mars goes round the ſun in 1 year 321 days 17 hours: its diameter is 5400 miles, its diſtance from the ſun is 145,014,148 miles; its hourly motion in its orbit is 55,287 miles; and it turns round its axis in 24 hours 40 minutes.

Jupiter goes round the ſun in 11 years 314 days 18 hours: its diameter is 94,000 miles, its diſtance from the ſun is 494,990,976; its hourly motion in its orbit is 29,083 miles, and it turns round its axis in 9 hours 56 minutes.

Jupiter's neareſt moon goes round it in 1 day 18 hours 36 minutes; its next, or ſecond moon, in 3 days 13 hours 15 minutes; its third moon, in 7 days 3 hours 59 minutes; and its fourth in 16 days 18 hours 30 minutes.

Saturn goes round the ſun in 29 years 167 days: its diameter is 78,000, miles excluſive of its ring; its diſtance from the ſun is 907,956,130 miles, its hourly motion in its orbit is 22,102 miles: but the time of its rotation on its axis is unknown.

This planet has five moons, the neareſt of which goes round it in 1 day 21 hours 19 minutes, the ſecond in 2 days 17 hours 40 minutes, the third in 4 days 12 hours 25 minutes, the fourth in 15 days 22 hours 41 minutes, and the fifth in 79 days 7 hours 48 minutes.

If a body, projected from the ſun, ſhould continue to fly at the rate of 480 miles every hour (which is about the ſwiftneſs of a cannon ball) it would reach the orbit of *Mercury* in 8 years 276 days; of *Venus* in 16 years 136 days; of *the Earth* in 22 years 226 days; of *Mars* in 34 years 169 days; of *Jupiter* in 117 years 234 days; of *Saturn* in 215 years 287 days; and to the neareſt of the *fixed ſtars* in about 8 millions of years.

From the times in which the planets are obſerved to go round the ſun, and the univerſal power of gravity by which they are retained in their orbits, it is demonſtrable, that if the earth's mean diſtance from the ſun be divided into 100,000 equal parts, Mercury's mean diſtance from the ſun muſt be equal to 38,710 of theſe parts; Venus's mean diſtance, 72,333; Mars's, 152,369; Jupiter's, 520,096; and Saturn's 954,006.

Hence, if we know the real diſtance of any planet from the ſun in miles, we may find the diſtances of all the reſt by the above numbers. Now, by the tranſit of Venus in June 1761, the earth's mean diſtance from the ſun was found to be 95,173,000 miles; and therefore, the mean diſtances of all the reſt of the planets from the ſun muſt be as above mentioned.

And, when the diſtance of any object is known, there are eaſy rules in geometry to know its real diameter, or bulk, from its apparent.

Now let us ſuppoſe that an *Orrery* is intended to be made, in which the ſun and planets ſhall be repreſented in their proportional magnitudes, and the planets at their proper diſtances from the ſun in proportion to their magnitudes; the ſun's diameter being 12 inches.

In this caſe, the diameter of *Mercury* would be $\frac{42}{1000}$ parts of an inch ; the diameter of *Venus* $\frac{126}{1000}$ parts; the diameter of *the Earth* $\frac{107}{1000}$ parts ; the *moon*'s diameter $\frac{29}{1000}$ parts; *Mars*'s diameter $\frac{73}{1000}$ parts ; *Jupiter*'s diameter 1 inch and $\frac{267}{1000}$ parts; and *Saturn*'s 1 inch and $\frac{52}{1000}$ parts.

Then, the true proportional diſtances of theſe planets from the ſun would be as follows: *Mercury*'s diſtance 41 feet; *Venus*'s 77, *the Earth*'s 107; the *Moon's* diſtance from the *Earth* $3\frac{23}{100}$ inches; *Mars*'s diſtance from the ſun 163 feet; *Jupiter*'s, 556; and *Saturn*'s, 1020.—Conſequently, there can be no ſuch thing as having the ſun and planets of their relative magnitudes, and at their proportional diſtances, in an *Orrery*; even though the earth's diameter ſhould be no more than the ninth part of an inch.

The ſun's light diminiſhes in proportion as the ſquare of the diſtance from him increaſes. At *Mercury*, the ſun's light is almoſt ſeven times as great as it is at the earth: at *Venus* almoſt twice as great: at *Mars* it is not quite half ſo great as at the earth: at *Jupiter* it is but a 25th part ſo great as at the *Earth*; at *Saturn*, only 100dth part.

The earth by its annual motion round the ſun, is 190 millions of miles nearer ſome of the ſtars at one time of the year than at another: and yet, the apparent magnitudes of theſe ſtars, and their angular diſtances from each other, is ſtill the ſame. This proves, that if the earth were 190 millions of miles in diameter, it would appear no bigger than a mere dimenſionleſs point, if viewed from any ſtar; and conſequently, that the diſtance of the ſtars from us is inconceivably great.

At the diſtance of any ſtar, all the planets in our ſyſtem would be inviſible; and the ſun would appear no bigger than a common ſtar does to us, conſequently each ſtar may be a ſun to a ſyſtem of planetary worlds, which our beſt teleſcopes cannot poſſibly diſcover.

The ſtars are vaſtly too remote from the ſun, to be enlightened by him, ſo as to reflect light enough to make them viſible. Hence it is plain that they ſhine by their own native and unborrowed luſtre.

Thoſe of the firſt magnitude cannot be leſs than the ſun; otherwiſe they could not appear ſo large as they do.—But, as they are ſo large, and ſhine by their own light, they are ſuns.

'Tis probable that all the reſt are as large, and only appear to be of different and leſſer magnitudes on account of their different diſtances.

The number of ſyſtems which would ſtand around our ſolar ſyſtem, and next to it, is much leſs than the number of thoſe which might ſtand next around them: and ſo on to infinity. And, the ſtars of the firſt magnitude are of a much leſs number than thoſe of the ſecond: thoſe of the ſecond much leſs in number than thoſe of the third; and ſo on.

This circumſtance makes it highly probable, that the ſtars which appear to be the biggeſt are ſuns to thoſe ſyſtems of planets next around our ſyſtem; thoſe of the ſecond magnitude, ſuns to thoſe ſyſtems next beyond our neighbouring ſyſtems: and ſo on to the ſtars of the ſixth magnitude, which are the ſmalleſt that the bare eye can perceive.

By means of the teleſcope, thouſands of ſtars are ſeen, which are quite inviſible to the bare eye. Thoſe are of no manner of uſe to us, but we cannot therefore conclude that they are altogether uſeleſs: and therefore we infer, that each ſtar is a ſun to a particular ſyſtem of worlds.

LECTURE X.

On the SEASONS, *and* LONGITUDE.

THE *axis* of any planet is the line round which the planet turns: and the extremities of that line, at the planet's ſurface, are its *poles*.

The earth's motion on its axis is the cauſe of day and night. Its turning round every 24 hours produces the ſame effect as if the ſun moved round it in that time.

The earth's axis inclines 23½ degrees from a perpendicular to the ecliptic, in which it moves round the ſun. Therefore, the earth's poles can never incline more than 23½ degrees either toward or from the ſun.

The obliquity of the earth's axis, and its conſtant paralleliſm throughout its whole annual courſe round the ſun, are the cauſes of the different ſeaſons, and the different lengths of days and nights.

The north pole of the earth's axis inclines more or leſs toward the ſun, from the vernal equinox to the autumnal; and more or leſs from the ſun, from the autumnal equinox to the vernal. In the former caſe, it is the ſummer half-year in the northern hemiſphere of the earth; and in the latter caſe, the winter half-year: and the contrary in the ſouthern hemiſphere of the earth. For, when the north pole inclines toward the ſun, the ſouth pole declines from him; and *vice verſa.*

In the northern hemiſphere the vernal equinox (or equal day and night in the ſpring) is on the 20th of *March*; and the autumnal equinox (or equal day and night in autumn) is on the 23d of *September*. In the ſouthern hemiſphere, the contrary.

The earth goes round the ſun every year in the ecliptic: and therefore, the ſun appears to us to go round the ecliptic in that time. And in whatever point of the ecliptic the earth is, at any time, as ſeen from the ſun, the ſun's center will then appear to us to be in the oppoſite point of the ecliptic.

The equator is a great circle, all around the earth; and it divides the earth into two equal parts, called the northern and ſouthern hemiſpheres. The north pole is the middle point of the northern hemiſphere, and the ſouth pole is the middle point of the ſouthern.—The equinoctial circle in the heaven is directly over the earth's equator, and it divides the heaven into two equal parts, called the northern and ſouthern hemiſpheres. The north and ſouth poles of the heaven are directly over the north and ſouth poles of the earth.

At the equinoxes, when the ſun appears to be in the equinoctial circle, the earth's axis inclines neither toward him nor from him, but ſideways to him. At the ſolſtices, which are the middle days of ſummer and winter, the relative *pole* inclines 23½ degrees toward or from the ſun; and then he is 23½ degrees from the equinoctial.

When the ſun is in the equinoctial, he enlightens the earth juſt from pole to pole.—At all other times, he ſhines as many degrees round the pole which inclines toward him, as he is diſtant from the equinoctial toward that pole: and the oppoſite pole is then juſt as many degrees involved in darkneſs.—Thus, the ſun ſhines round each pole, in its turn, for half a year together, and is juſt as long withdrawn from it: ſo that, at the poles of the earth there is but one day and one night in the whole year.

The *northern tropic*, called the *Tropic of Cancer*, is a circle 23½ degrees from the equator, on the north ſide; and the *ſouthern tropic*, called the *Tropic of Capricorn*, is a circle 23½ degrees from the equator, on the ſouth ſide. The ſun is in the Tropic of *Cancer* on the 20th of *June*, and in the Tropic of *Capricorn* on the 20th of *December*, as ſeen from the earth.

The *polar circles* are 23½ degrees from the poles, all around them. When the ſun is in the northern tropic, the whole ſpace within the north polar circle is enlightened, and all within the ſouth polar circle is in darkneſs; the contrary when the ſun is in the ſouthern tropic; as is plainly ſhewn by the *Orrery*.

The meridian of any place is a ſemicircle paſſing through that place, cutting the equator at right angles, and ending at the poles.

The earth's circumference is 360 degrees: and, as it turns round its axis in 24 hours, each meridian revolves 15 degrees in an hour: for 24 times 15 is 360.

Every place, whoſe meridian is 15, 30, 45, 60, or 75 degrees eaſtward (and ſo on, increaſing by 15) from the meridian of any given place, has noon, and every other hour, one, two, three, four, or five hours (and ſo on in proportion) ſooner than the given place has the like hour: if weſtward, ſo much later.

The longitude of any place is the number of degrees intercepted between its meridian and the meridian of any given place from which the longitude is reckoned: and is eaſt or weſt, according as that place is eaſt or weſt from the meridian of the given place.

The eclipſes of *Jupiter*'s moons afford a method for finding the longitude, according to the obſerved times of their happening, as ſeen from different parts of the earth. Thus, ſuppoſing ſuch an eclipſe to happen at ſix in the morning at *London*, and that it was ſeen at another place at four in the morning; the difference of time is two hours, which anſwers to 30 degrees. Conſequently, the meridian of the place, where the eclipſe was ſeen at four in the morning, is 30 degrees weſt from the meridian of *London*, were the ſame eclipſe was ſeen at ſix in the morning.

Theſe eclipſes ſhew, that the motion of light is not inſtantaneous; but that it takes about 16 minutes to travel through a ſpace equal to the diameter of the earth's orbit. For when *Jupiter* is nearly in conjunction with the ſun (that is, when the ſun is nearly between the earth and *Jupiter*) theſe eclipſes happen 16 minutes later than when *Jupiter* is oppoſite to the ſun, which is, when the earth is between the ſun and *Jupiter*. In the latter caſe, the earth is nearer to *Jupiter* by the whole diameter of its orbit (which is 180,346,000 miles) than in the former. Therefore, as the ſun is nearly in the center of the earth's orbit, and his mean diſtance from the earth is 95,173,000 miles; and, as light moves through a ſpace equal to the diameter of the earth's orbit in 16 minutes, it moves from the ſun to the earth in 8 minutes; which is with a ſwiftneſs 1,487,078 times as great as a cannon ball flies. — Hence it appears, that light moves 713,797,500 miles in an hour; 11,896,625 miles in a minute; and 198,277 miles in a ſecond, which is 11848 times as faſt as the earth moves in its annual orbit.

LECTURE XI.

On the MOTIONS *and* PHASES *of the* MOON.

THE moon turns round her axis in the time that ſhe goes round her orbit, and therefore, ſhe always keeps the ſame ſide toward the earth.

Her periodical revolution, or time of going round from any point of her orbit to the ſame point again, is 27 days 7 hours 43 minutes.

Her ſynodical revolution, or time from change to change, is 29 days 12 hours 43 minutes 3 ſeconds; which is the length of her day and night taken together: for, as ſeen from the ſun, ſhe turns only once round her axis in that time.

If the earth had no progreſſive (or annual) motion round the ſun, the ſame point of the moon's orbit would always keep between the earth and the ſun; and then, there would be no difference between her periodical and ſynodical revolution; for ſhe would always change in the ſame point of her orbit.

But, as the earth is in continual motion round the ſun, and the ſigns of the moon's orbit always keep parallel to the like ſigns of the fix'd ecliptic; a different part of the moon's orbit will be every day between the earth and the ſun from that point which was ſo on the day before: and therefore, the moon muſt move as many degrees more than round her orbit, between any change and the next following, as the earth has advanced in the ecliptic during that time; which is $29\frac{1}{10}$ degrees.

As the moon goes quite round her orbit in 27 days 7 hours 43 minutes, and the earth goes round the ſun but once a year; the earth's axis has all the different poſitions to the moon in the time ſhe goes round her orbit, that it has to the ſun in a year.

The moon ſhines only by reflecting the ſun's light: for, if ſhe were a luminous body, ſhe would always appear round, as the ſun does.

A luminous body can enlighten only one half of an opaque globe at once: and therefore, at any given moment, the ſun can enlighten only one half of the moon.

When the moon is between the earth and the ſun, ſhe diſappears; becauſe her un-enlightened ſide is then toward the earth. When ſhe is oppoſite to the ſun, ſhe appears full; becauſe her whole illuminated ſide is then toward the earth. When ſhe is 90 degrees, or a quarter of a circle, diſtant from the ſun, ſhe appears half full; becauſe only one half of her enlightened ſide is then toward the earth.

The earth and moon are mutually moons to each other: but the earth gives thirteen times as much light to the moon as the moon gives to the earth; for, the earth's ſurface is thirteen times as large as the moon's.

In conſiderable latitudes, the different *ſigns* of the ecliptic riſe at very different angles with the horizon. In northern latitudes, the ſigns *piſces* and *aries* riſe with the ſmalleſt angles; *virgo* and *libra* with the greateſt.—Therefore,

When the moon is in *piſces* and *aries*, ſhe riſes nearly at the ſame hour for ſix or ſeven days togeter: but, when ſhe is in *virgo* and *libra*, ſhe riſes ſo much later every day, as to differ eight hours in ſix or ſeven days.

In our winter, the moon is in *piſces* and *aries* in her firſt quarter, and then ſhe riſes about noon: but her riſing at that time is not taken notice of, becauſe the ſun is above the horizon.

In ſpring, ſhe is in *piſces* and *aries* about the time of her change: and as ſhe is then inviſible her riſing cannot be perceived.

In ſummer, ſhe is in *piſces* and *aries* about the time of her third quarter: and then as ſhe does not riſe till about midnight, her riſing paſſes unobſerved; eſpecially as ſhe is ſo much on the decreaſe.

In autumn, *piſces* and *aries* are oppoſite to the ſun; and therefore, the moon is then full in them, and riſes immediately after ſun-ſet for ſeveral evenings together; which makes her riſing very conſpicuous, as it is ſo beneficial to the farmers, in affording them an immediate ſupply of light after ſun-ſet, for reaping the fruits of the earth.

LECTURE XII.

On ECLIPSES, &c.

ALL the planets and ſatellites are enlightend by the ſun, and caſt ſhadows toward that part of the heaven which is oppoſite to the ſun as ſeen from them.

If the ſun and earth were equally big, the earth's ſhadow would be infinitely extended, and always of the ſame bulk; and would cover the planet *Mars* when it is oppoſite to the ſun.

If the earth were bigger than the ſun (and to us it ſeems to be the biggeſt body in the univerſe) its ſhadow would ſtill be the bigger the farther it extended; and would cover *Jupiter* and all his moons when *Jupiter* were oppoſite to the ſun.

If the ſun be bigger than the earth, the ſhadow of the earth will be of a conical figure; and end in a point at a certain diſtance from the earth.

But the earth's ſhadow never reaches *Mars*, although that planet, when oppoſite to the ſun, is not quite 50 millions of miles from the earth, which demonſtrates that the ſun is much bigger than the earth.

The moon is eclipſed when ſhe falls into the earth's ſhadow.—Therefore, ſhe can never be eclipſed but when ſhe is full; becauſe that is the only time when ſhe can be oppoſite to the ſun. If ſhe were a luminous body, ſhe could not be darkened by the earth's ſhadow. For, a candle will ſuffer no diminution of its brightneſs by being placed in the ſhadow of a board or globe, enlightened on the oppoſite ſide by another candle.

The ſun is ſaid to be eclipſed when the moon paſſeth directly between him and any part of the earth; which can only be at the time of new moon.

But although the moon may then ſtop the ſun's light from a ſmall part of the earth, and *that* part muſt be darkened, becauſe the moon's ſhadow covers it: yet as ſhe does not take a ſingle ray of light from the ſun; ſtrictly ſpeaking, the ſun is never eclipſed by the moon, any more than he is by the convexity of the earth when it hides him from our ſight. — Notwithſtanding, when the moon hides the whole or any part of the ſun from our ſight, we ſay, the ſun is then eclipſed.

If the moon's orbit lay in the * plane of the ecliptic (in which the earth always moves) the ſun would be eclipſed at the time of every new moon: and the moon would be eclipſed at the time of every full.

But, one half of the moon's orbit is on the north ſide of the plane of the ecliptic, and the other half is on the ſouth ſide of it. Therefore the moon's orbit cuts the plane of the ecliptic only in two oppoſite points, which are called *the moon's nodes*. The angle which the moon's orbit makes with the ecliplic is 5 degrees 18 minutes.

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* If a circle be drawn upon a piece of flat paper, the paper may be called the plane of that circle.

When the moon is any more than 12 degrees from either of her nodes at the time of being full, ſhe paſſeth clear of the earth's ſhadow; and therefore ſhe cannot be eclipſed at that time. But, when ſhe is within 12 degrees of either node at full, ſhe is eclipſed; and if ſhe be in either of the nodes when full, the eclipſe will be central.

When the moon is any more than 18 degrees from either of her nodes at the time of change, ſhe paſſeth either above or below the ſun; and no part of the ſun can be eclipſed by her at that time. But when ſhe is within 18 degrees of either of her nodes at the time of change, ſhe eclipſeth the ſun to ſome part of the earth. And if ſhe be in the node, the eclipſe will be central to that point of the earth's ſurface, which is in a right line between the ſun's center and the earth's.

If the moon's nodes had no motion through the ſigns of the ecliptic, in whatever ſigns the ſun and moon were eclipſed in any given year, they would be ſo in every year after.—But the eclipſes fall ſo much back every year from the conſequent toward the antecedent ſigns, as to prove that the nodes move backward 19 $\frac{1}{3}$ degrees every year. And therefore, in 18 years 225 days they go backward through the whole ecliptic.

From the time of the ſun's being in conjunction with either of theſe nodes to the time of his being in conjunction with the other, is 173 days. If the nodes had no motion, the interval between theſe conjunctions would be 182$\frac{1}{2}$ days, or half a year.

Always, in 18 years 11 days 7h. 43 min. there is a conjunction of the ſun and moon with the ſame node: and therefore, in that time, there is a period or reſtitution of the ſame eclipſes.

The darkneſs at our SAVIOUR's crucifixion could not poſſibly be occaſioned by a natural or regular eclipſe of the ſun: for it was at the time of the paſſover, and the paſſover was always kept at the time of full moon.

He was crucified on the day next before the Jewiſh Sabbath, which being kept on our *Saturday*, the Crucifixion was on a *Friday:* So that the paſſover full moon in *that* year was on a *Friday.*—But it appears, by calculation, that there was only one paſſover full moon on a *Friday* from the 20th to the 40th year of our Saviour, accounted from the vulgar æra of his birth: and *that* particular full moon was on the third day of *April*, in the 33d year of his age, reckoned from that æra.

The 33d year of Chriſt was the fourth year of the 202d *Olympiad*. And *Phlegon*, a heathen writer, tells us, that "in the fourth year of the 202d "*Olympiad*, there was the greateſt eclipſe of the "ſun that ever was known; for the day was turned "into night for three hours, and the ſtars in the "heaven were ſeen."

Ptolemy's canon fixes the year, in which the commandment was given to *Ezra* by *Artaxerxes Longimanus*, to reſtore and build *Jeruſalem*, to the 457th year before the vulgar æra of Chriſt's birth: and, according to *Daniel's* prophecies, the death of Chriſt was to be at the end of 70 weeks [of years] or 490 years after the time when that commandment was given.

And 33 years being added to 457, makes up the whole 490; that is, from the year of the commandment to the 33d year of Chriſt; which we prove by aſtronomy to have been the year of his death; concerning which, we have the teſtimony of a heathen writer; who, being not an aſtronomer, miſtook a ſupernatural darkneſs for an eclipſe of the ſun.

FINIS.